ADAPTIVE CONTROL OF A CONSTRUCTION MANIPULATOR

by

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ABSTRACT: The paper describes an advanced control technique that uses a self-adjusting controller. The technique allows changing control parameters of the manipulator according to different technological forces and disturbances acting to the end-effector of the manipulator while performing surface treatment construction operations such as cleaning and polishing. The system is asymptotically stable for the phase error and can be implemented on a base of existed industrial robots.

KEYWORDS: adaptive control; construction manipulator, parametrical error; reference model; self-adjusting controller.

1. INTRODUCTION

Automation of some surface treatment construction operations such as cleaning and polishing by means of manipulators demands adaptive control that allows keeping required technological forces of a tool at any disturbances from surface unevenness.

There is a program that allow for efficient management of relevant operational parameters related to surface finish quality [1]. This program is intended for on-board computers in graders or pavers.

One of approaches in manipulator control is based on a calculation method by incomplete information about external parameters [2]. However, the known algorithm of control is characterized by complexity of calculations and is usually used for manipulators with two or three degrees of freedom.

Optimal positioning of a pneumatic manipulator with minimum control energy consumption is solved in [3]. This system can place a tool with high accuracy taking into account information about current position of the manipulator but some disturbances can act to the tool from treated surface unevenness while operating.

The proposed technique solves a task of qualitative control of the manipulator tool with a reference model where a wide range of possible dynamic properties can be changed. The technique allows changing control parameters of the manipulator according to different technological forces and disturbances acting to the end-effector of the manipulator while performing surface treatment construction operations such as cleaning and polishing by means of a self-adjusting manipulator controller.

2. SYSTEM WITH A REFERENCE MODEL

Let's consider the approach based on the self-adjusting system with a reference model on the basis of information about object parameters that is received while functioning. The active change of regulator parameters should be carried out on a base of this information.

The self-adjusting system with the reference model can be described by the block diagram presented in Figure 1.

The system motion is described by the linear n-order differential equation with constant beforehand-unknown factors, which can vary in a wide range scale

$$x^{(n)}(t) + \sum_{i=1}^{n}[a_i + \Delta a_i + \delta\, a_i(t)]x^{(n-i)}(t) = = f(t), \tag{1}$$

where Δa_i - constant beforehand-unknown factors, $\delta\, a_i(t)$ - factors, generated by the self-adjusting circuit.

The reference model is described by the equation:

$$y^{(n)}(t) + \sum_{i=1}^{n} a_i y^{(n-i)}(t) = f(t), \tag{2}$$

where $y(t)$ - output signal of the reference model, $f(t)$ - control signal. It is supposed that the reference model is asymptotically steady.

The purpose the system with the reference model is to design such a self-adjustment circuit, at which $x(t) \to y(t),\ t \to \infty$ by generated $\delta\, a_i(t)$. The equations of the object and the reference model in the matrix form are

$$\dot{x}(t) = Ax(t) + \left[\Delta A + \delta\, A(t,x,y)\right]x(t) + + f(t), \quad x(t_0) = x_0, \tag{2}$$

$$\dot{y}(t) = Ay(t) + f(t), \quad y(t_0) = y_0, \tag{3}$$

where $x(t),\ y(t) \in R^n$ - phase coordinate vectors of the object and the reference model, A - a real constant matrix (Gurvitz matrix) that can be written as

$$A = \begin{bmatrix} 0 \;\; 1 \;\; 0 \; \ldots \; 0 \\ \ldots\ldots\ldots\ldots\ldots \\ 0 \;\; 0 \;\; 0 \ldots \; 1 \\ a_1\; a_2\; a_3 \ldots\; a_n \end{bmatrix}, \tag{4}$$

ΔA - real constant matrix with beforehand-unknown factors depending on the control object, $\delta\, A(t,x,y)$ - matrix of parameters changed by the self-adjustment circuit. The matrixes ΔA and $\delta\, A$ can be expressed as

$$\Delta\, A = \begin{bmatrix} 0 \quad \ldots \quad 0 \\ \ldots\ldots\ldots\ldots \\ 0 \quad \ldots \quad 0 \\ \Delta a_1 \ldots \Delta a_n \end{bmatrix},$$

$$\delta\, A(t,x,y) = \begin{bmatrix} 0 \quad \ldots \quad 0 \\ \ldots\ldots\ldots\ldots \\ 0 \quad \ldots \quad 0 \\ \delta\, a_1 \ldots\, \delta\, a_n \end{bmatrix}. \tag{5}$$

The control vector is $f^T(t) = (0, \ldots, 0, f_n(t))$, where the top index hereinafter means a transpose operation. For an error vector $\varepsilon(t) = x(t) - y(t)$, subtracting equations (3) from (2), we have

$$\dot{\varepsilon}(t) = A\varepsilon(t) + \left[\Delta A + \delta\, A(t,x,y)\right]x(t), \quad \varepsilon(t_0) = \varepsilon_0 \tag{6}$$

or in more convenient form

$$\dot{\varepsilon}(t) = A\varepsilon(t) + X(t)\alpha(t,x,t), \quad \varepsilon(t_0) = \varepsilon_0 \tag{7}$$

where $X(t)$ - matrix, at which the last row coincides with the vector $x^T(t)$, and $\alpha(t,x,y)$ - vector of a parametrical error

$$\alpha^T(t,x,y) = \\ = \left(\Delta a_1 + \delta a_1(t,x,y),...,\Delta a_n + \delta a_n(t,x,y)\right).$$

The Lyapunov´s second theorem is used for a synthesis of the self-adjustment circuit. Let's choose Lyapunov´s function as the square-law form

$$V(t,\varepsilon,\alpha) = \varepsilon^T \Gamma \varepsilon + \alpha^T \alpha, \quad (8)$$

where the positively certain matrix Γ satisfies to the matrix equation

$$A^T \Gamma + \Gamma A = -CE.$$

The equation of the self-adjustment circuit is

$$\dot{\alpha}(t) = \theta(t,\varepsilon,x,y).$$

A derivative of the V function by this equation should be not positive, i.e.

$$\frac{dV}{dt} \le 0.$$

The derivative of the function (8) by system (7) is equal

$$\dot{V} = -C|\varepsilon|^2 + \alpha^T X^T \Gamma \varepsilon + \varepsilon^T \Gamma X \alpha + \\ + \dot{\alpha}^T \alpha + \alpha^T \dot{\alpha} = -C|\varepsilon|^2 \le 0, \quad (9)$$

if the self-adjustment circuit is described by the following equation

$$\dot{\alpha}(t) = -X^T(t)\Gamma\varepsilon(t). \quad (10)$$

The algorithm (10) covers the majority of known algorithms of adaptation. If vectors $x(t)$, $y(t)$, $\varepsilon(t)$ are measurable, the algorithm (10) can be implemented. Thus, the system (7), (10) is stable for $\varepsilon(t)$ and $\alpha(t)$.

3. DEFINITION OF THE SELF-ADJUSTMENT CIRCUIT VECTOR

In practice, there are objects, in which the matrix of factors depends on some number of parameters. Let the object is described by the equation

$$\dot{x}(t) = A(q)x(t) + \delta Z(t) + f(t), \quad x \in R^n, \quad (11)$$

and the reference model is described by the equation

$$\dot{y}(t) = A(q^0)y(t) + f(t), \quad y \in R^n, \\ f(t) \in R^n \quad (12)$$

where $q \in R^m$ - the vector of parameters, from which a matrix of object is depended, $A(q^0)$ - Gurvitz matrix, $\delta Z(t)$ - vector generated by the self-adjustment circuit. The task consists in definition of structure and algorithm of change of the vector $\delta Z(t)$ to have $\varepsilon(t) = x(t) - y(t) \to 0$, $t \to \infty$. The vector of a phase error $\varepsilon(t)$ satisfies to the equation

$$\dot{\varepsilon}(t) = A(q^0)\varepsilon + \left[A(q) - A(q^0)\right]x(t) + \\ + \delta Z(t). \quad (13)$$

Decomposing $A(q)$ in a row, we have

$$A(q)-A(q^0)=\sum_{i=1}^{m}\Delta q_i\frac{\partial A(q)}{\partial q_i}+O(|\Delta q|),$$
$$q-q^0=\Delta q,\quad \Delta q\in R^m, \qquad (14)$$

where values of derivatives in (13) are calculated for $q=q^0$.

Let's enter the vector $\delta Z(t)$, generated by the self-adjustment circuit, as

$$\delta Z(t)=\sum_{i=1}^{m}\delta q_i(t)B_i(t),$$
$$B_i(t)=\frac{\partial A(q)}{\partial q_i}\Big|_{q=q^0}x(t) \qquad . \qquad (15)$$

Here $\delta q_i(t)$ - scalar functions that is determined below.

Taking into account expressions (14) and (15), equation (13) is possible to write as

$$\dot{\varepsilon}(t)=A(q^0)\varepsilon(t)+$$
$$+\sum_{i=1}^{m}(\Delta q_i+\delta q_i)\frac{\partial A}{\partial q_i}x(t)+O(|\Delta q|)x(t). \qquad (16)$$

Let's assume, that the matrix $A(q)$ depends on the parameter q linearly. Then, last member in the equation (16) is absent and it will have a form

$$\dot{\varepsilon}(t)=A(q^0)\varepsilon(t)+\sum\beta_i(t)\frac{\partial A}{\partial q_i}x(t) \quad ,$$
$$\beta_i(t)=\Delta q_i+\delta q_i(t). \qquad (17)$$

The further synthesis of the self-adjustment circuit uses Lyapunov´s function. It can be chosen as

$$V(t,\varepsilon,\beta)=\varepsilon^T\Gamma\varepsilon+$$
$$\sum_{i=1}^{m}\beta_i^2(t),\ \Gamma>0,\ \Gamma=\Gamma^T, \qquad (18)$$

where the matrix function Γ generally looks like $\Gamma=\Gamma(t,x,y)$.

A complete derivative of this function, taking into account equations (17), is

$$\frac{dV}{dt}=\varepsilon^T(A^T(q^0)\Gamma+\Gamma A(q^0)+\dot{\Gamma})\varepsilon+$$
$$\sum\beta_i(t)(B_i^T\Gamma\varepsilon+\varepsilon^T\Gamma B_i+2\dot{\beta}_i(t)) \qquad . \qquad (19)$$

Since a matrix Γ is symmetrical, we have $B_i^T\Gamma\varepsilon=\varepsilon^T\Gamma B_i$. Let's consider the following algorithm of adjustment of parameters $\delta q_i(t)$

$$\frac{d}{dt}(\delta q_i(t))=\dot{\beta}_i(t)=-B_i^T\Gamma\varepsilon=$$
$$=-x^T(t)\left(\frac{\partial A}{\partial q_i}\right)^T\Gamma\varepsilon \qquad . \qquad (20)$$
$$\beta_i(0)=\Delta q_i,\ \delta q_i(0)=0$$

Let matrix $\Gamma(t,x,y)$ satisfies to conditions

$$C_1|p|^2\le p^T\Gamma(t,x,y)\le C_2|p|^2$$
$$p^T(A^T\Gamma+\Gamma A+\dot{\Gamma})\le -C_3|p|^2, \qquad (21)$$

in which $A=A(q^0)$, the matrix $A(q)$ linearly depends on parameters, $A(q^0)$ - Gurvitz matrix. Then it is possible to show, that the system (17), (20) is stable for $\varepsilon(t)$ and $\beta_i(t)$, and also is asymptotically stable for the phase error. If the matrix $A(q)$ depends on parameters not linearly, the system may be not stable.

However, described self-adjustment circuit has the following property. If the control signal is restricted, the phase error is also limited, and the error can be so small as desired, if the parametrical error between the object and the reference model is small enough. It results from general stability theorems.

4. CONCLUSIONS

The advanced control technique that uses the self-adjusting controller is developed. The technique allows changing control parameters of the manipulator according to different technological forces and disturbances acting to the end-effector of the manipulator while performing surface treatment construction operations such as cleaning and polishing.

The system is asymptotically stable for the phase error in a linear case. In non-linear case, the phase error is also limited, and the error can be so small as desired, if the parametrical error between the object and the reference model is small enough.

The described control technique can be implemented on a base of industrial robots RM-01 or PUMA 560 that has six rotary joints and can perform different construction operations with complex trajectories of the tool.

5. REFERENCES

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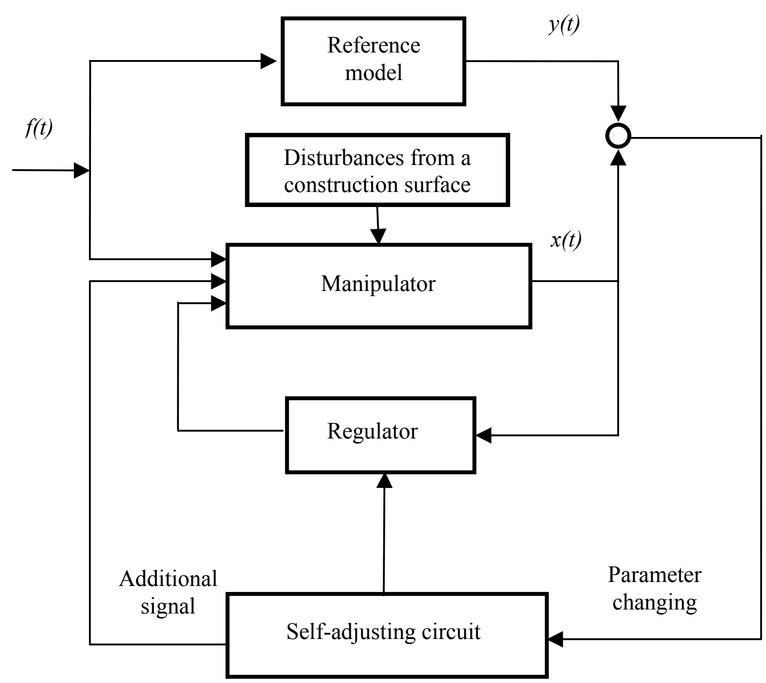

Figure 1. Self-adjusting system with the reference model